Wave Interaction with Large Topographic or Man-Made Structures

Chiang C. Mei
Department of Civil & Environmental Engineering
Massachusetts Institute of Technology
Cambridge MA, 02139
Phone: (617) 253 2994 Fax: (617) 253 6300 E-mail: ccmei@mit.edu

Grant #: N00014-89-J-3128, ASSERT: N00014-95-1-0840

LONG-RANGE GOALS

Our goals are to understand the basic mechanics of wave interactions with natural boundaries or man-made structures near the coastline and to develop mathematical models that predict the dynamic response of waves, structures and coastal morphology quantitatively. The man-made structures may be rigid or movable, such as harbors, storm gates or offshore platforms, and the natural structures may include ripples, sandbars or headlands near which sand erosion and deposition are main features.

OBJECTIVES

Our specific topics in this year are:

1. Extending our new theory of sandbars by accounting for both bedload and suspended load. This extension enables us to treat a wider range of sand sizes and/or wave intensity.

2. With a view to predicting the suspension and transport of cohesive sediments in shallow water, we are developing a new theory of wind/wave-induced vortices in shallow seas. In contrast to existing models of Langmuir circulation in deep water, the bottom boundary layer now plays a central role.

3. Nonlinear resonance of long-period oscillations in a partially enclosed water by short-period swells. Different from last year's emphasis we have redirected our efforts from narrow- to broad-banded incident seas.

APPROACH

1. *Sand Bar Formation with Bedload and Suspended Load*. In last year's report, we described the evolution of bars by considering the bedload to be dominant. This is appropriate for sufficiently coarse sand or weak waves. In nature beach sand consists of a wide range of sizes and waves shed vortices near the ripple crests, hence suspension is unavoidable. We have analyzed the available empirical data on the rate of resuspension in oscillating flumes and concluded that the rate of upward flux of suspended load is proportional to the square of the local shear stress. This flux condition is now incorporated in the sediment conservation law, in addition to terms representing the bedload transport.

2. *Wind, Waves and Langmuir Circulation in Shallow Seas*. Langmuir circulation is known to be vital to air-sea interactions where the dynamics is mostly confined near the sea surface. For

understanding how fine sediments are transported in shallow seas, the interaction among wind, waves, and the bottom boundary layer is crucial. We are developing a comprehensive theory with the following ingredients: (a) we model the effects of wind directly and predict both the wind-induced drift current and the energy input to the waves; (b) to match field situations we incorporate the existing models of turbulent benthic boundary layer. Specifically we adopt the well-known empirical relation between friction factor and local wave amplitude to find the friction velocity and the eddy viscosity. This enables us to find the wave energy dissipation rate in the bottom boundary layer, which negates the energy input from wind. The instability of vortical current throughout the depth is then calculated by modifying the Craik-Leibovich theory. Even in the initial stage of unstable growth the problem is nonlinear because of the nonlinear relation between bottom friction and wave amplitude.

3. *Long Wave Resonance of Harbors by Broad Banded Short Waves*. Last year we reported progresses made on the theory of long wave resonance in harbors by narrow banded short incident waves. It turns out that the narrow band assumption offers no theoretical/computational advantage. We have since revised our strategy and focus on the more general and practical case of broad-banded incident waves. At the first order the short waves are computed by the modified mild slope approximation, which can be effectively computed by the hybrid element method of Chen & Mei (1974). We have further extended the mild slope approximation to all sum and difference frequencies, which appear at the second order. The method will be later extended to incident wave with a broad and directional spectrum.

WORK COMPLETED

1. *Sand Bar Formation with Bedload and Suspended Load*. Mathiew Hancock, a new doctoral student, has succeeded in extending the bedload theory of Yu & Mei (2000) by incorporating the upward flux and suspended load. Some preliminary results are shown in the attached Figure 1, obtained for the steady state limit for bars formed on an otherwise horizontal seabed and under monochromatic surface waves. The input parameters are d=sand size, A_0=incident wave amplitude=0.35 cm, H=mean sea depth=11 m, and R=reflection coefficient=0.5. The forcing function and bar profiles h_s are compared for two sand sizes: d=0.02 cm (fine) and 0.006 cm (very fine) over the spatial range of half a wavelength. For the coarser sand (left column), contributions by suspended load are insignificant. The strongest forcing for accumulation, hence the bars crests, are found beneath the envelope minima. The bar troughs are found under the peaks of the envelope minima. For the finer sand forcing by the suspended load is comparable in magnitude but is opposite to the bedload. The resulting bar crests are shifted away from the envelope minima toward the maxima. These results are in qualitative agreement with the laboratory simulations of O'Hare and Davis (1992) in UK and of Rey in France. Indeed in their small setup (flume length ~ 5 m, water depth ~ 10 cm) the scaling effects are serious so that ripples are almost comparable in size as the bars, hence vortex shedding at the ripple crests is prominent so promotes suspension. Many new inquiries will be pursued immediately. Among them is the transient evolution of bars, since the time needed to reach the steady state is very long, during which the wave climate must change due to changing wind conditions or nonlinearity.

2. *Wind, Waves and Langmuir Circulation in Shallow Seas*. We have completed the linear instability theory, and conclude that turbulence in the benthic boundary layer renders dissipation nonlinear. Under wind forcing waves can grow or decay in time depending on water depth and wavelength. For the same wind speed Langumir cells grows faster for smaller initial waves. The size of the

most unstable cells changes with time, consistent qualitatively with the field observation of Smith (1992). Figure 2 shows the wave amplitude variation in time for different wind speed U_{10} and initial amplitude; Figure 3 gives the growth of drift current in water of depth h=6 m. Note that shear is strong not only near the top but also near the bed. Figure 4 a and b show for two different initial wave amplitudes but the same wind speeds the energy growth rate of typical Langmuir cells as functions of time and the cell size (represented by the horizontal wave number K_c).

3. *Long Wave Resonance of Harbors by Broad Banded Short Waves*. The analytical part is completed. Ms Mengyi Chen is now beginning to develop the computational schemes based on hybrid finite elements.

IMPACT/APPLICATIONS

1. *Sand Bar Formation with Bedload and Suspended Load*. With a complete model for both bedload and suspended load, the door is now open for many exciting inquiries. For example, in nature the sand size varies over a wide range. So under the same waves some are suspended and some are in bedload. The sand bar profile must depend on the distribution of sand sizes. Other topics include the beach slope and nonlinearity in water waves, such as harmonic generation and infra-gravity waves. The PI has been discussing possible collaboration with Professor Lev Shemer of Israel, who is interested in performing laboratory experiments at Tel Aviv University, where large wave facilities are available. Engineering applications of this knowledge include dredging, sand mining, and mine burials.

2. *Wind, Waves and Langmuir Circulation in Shallow Seas*. Langmuir cells have only been recently observed in a nearshore region (see http://www.me.berkeley.edu/faculty/szeri/pub.html ; website of Professor Andrew Szeri). The environmental importance of the fate of cohesive sediments is of interest to the transport of nutrients and toxic chemicals in, as well as the optical clarity of, coastal waters.

3. *Long Wave Resonance of Harbors by Broad Banded Short Waves*. In a report to the Port of Long Beach by the Technical Review Committee, this PI recently criticized the current approach of basing remedies on the linearized hypothesis that long period oscillations in harbors are the direct effects of long period incident waves (tsunami). As evidenced by the field records at Platform Edith, Long Beach Port is never threatened by tsunami but frequently by long groups of short waves. Similar to the slow-drift of floating platforms offshore, our new theory will give new tools to future harbor designers as well as planners for naval ship- to- shore operations.

REFERENCES

O'Hare and A.G. Davies, 1993. Sand bar evolution beneath partially standing waves: laboratory experiments and model simulation, *Continental Shelf Research*, 13, 1149-1181.

Yu, Jie, and C.C. Mei, 2000. Formation of sand bars under surface waves. *J. Fluid Mechanics*. 416, 315 348.

H.S. Chen and C.C. Mei, 1974. Oscillations and wave forces in a man-made harbor in an open sea, *Proc 10th Naval Hydrodynamics Symposium*, 573-594.

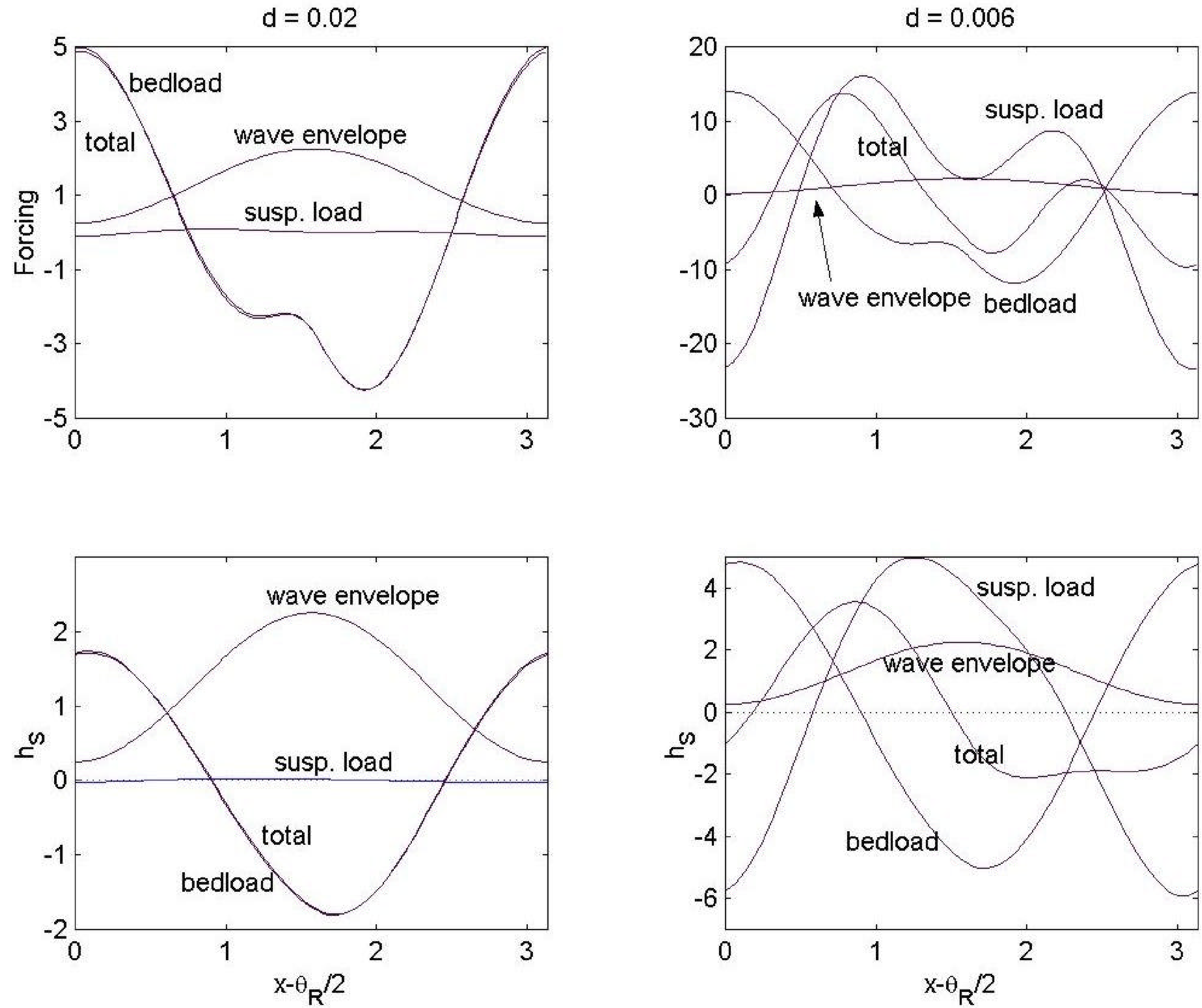

Figure 1. Steady-State Forcing and Bar Profiles for R=0.5, A_0=0.35 cm, H=11 m. Comparison of Fine (d=0.02 cm) and Very Fine (d=0.006 cm) Sands.

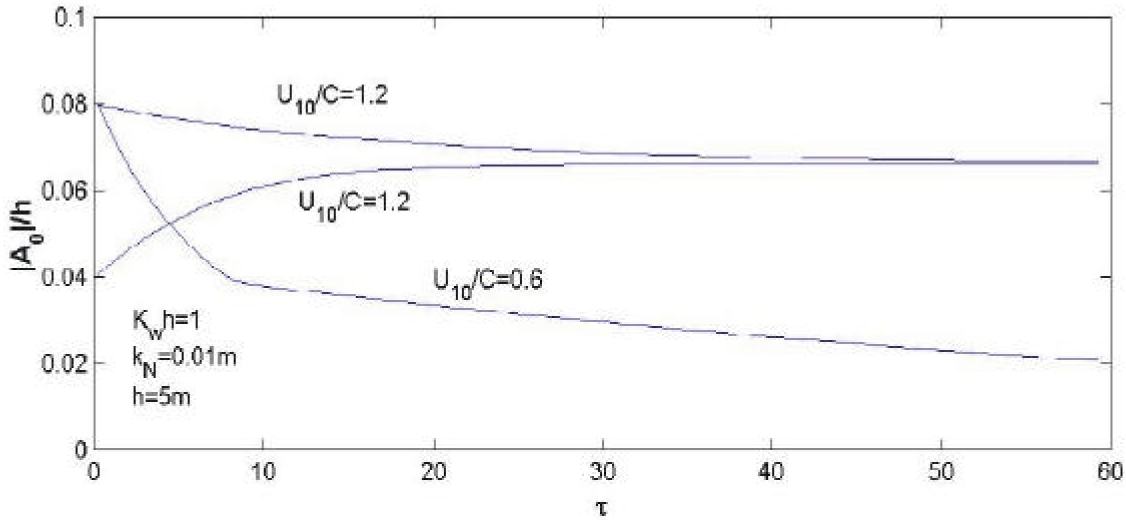

Figure 2. Time Variation of Wave Amplitude Under Different Wind Speeds and Initial Values.

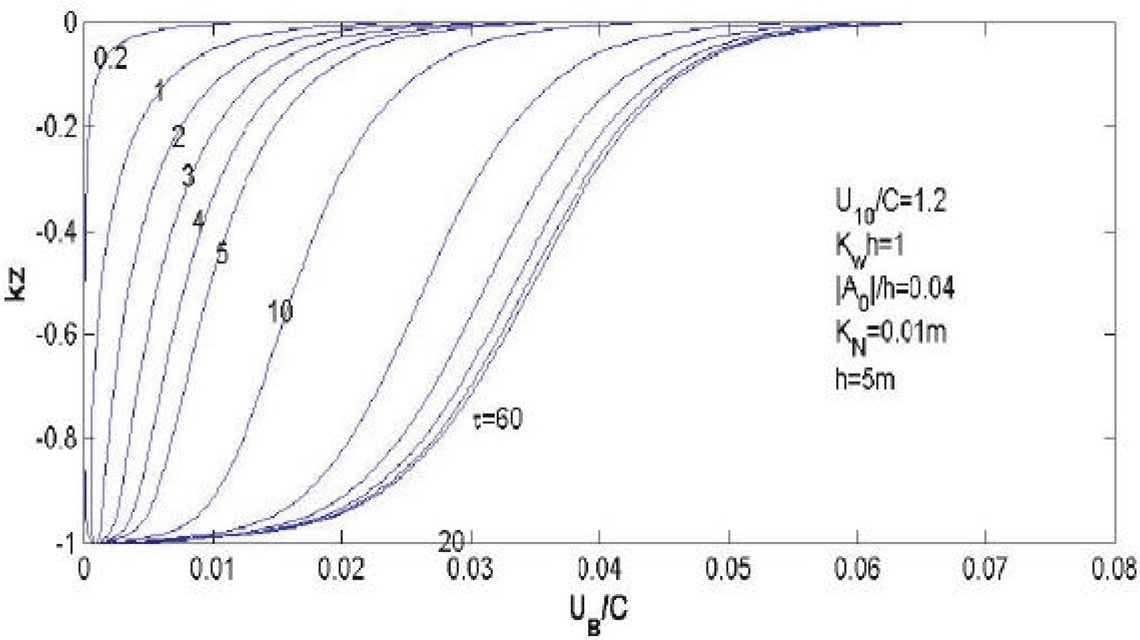

Figure 3. Time Evolution of Wind Induced Current.

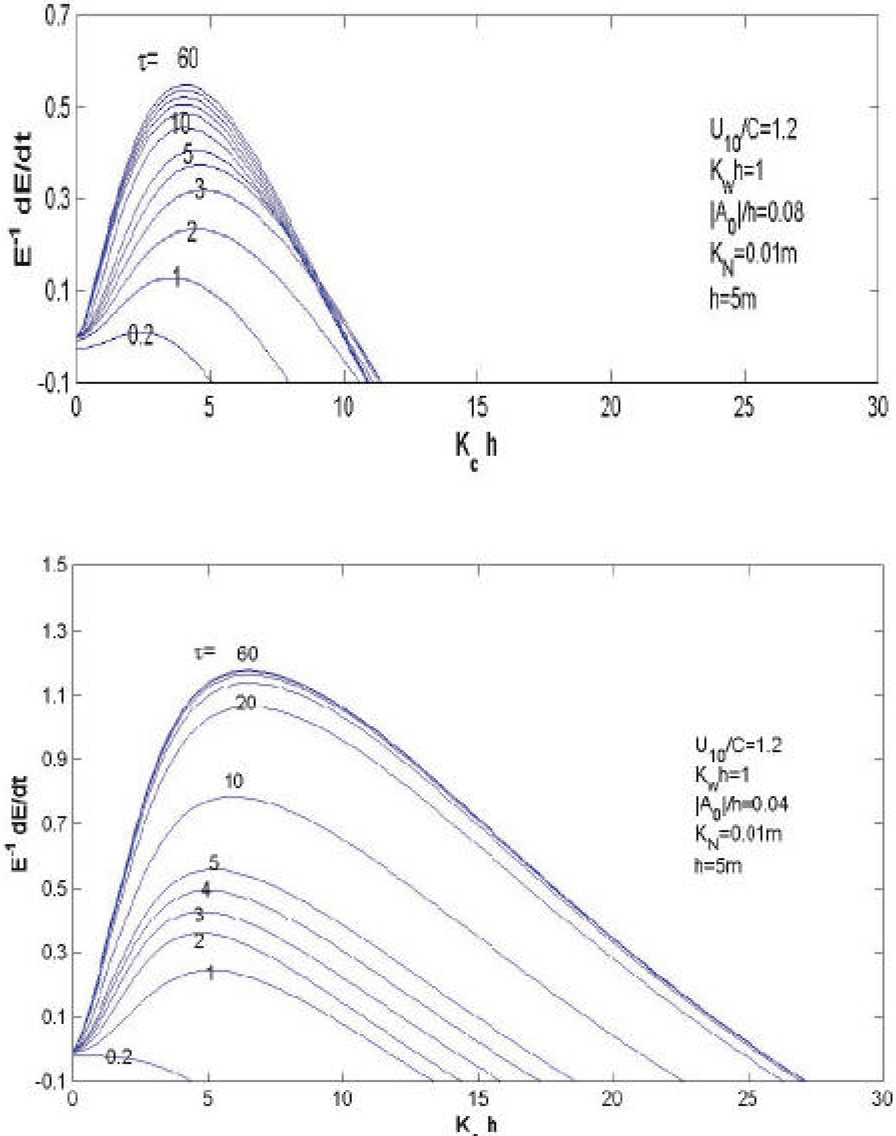

Figure 4. Growth Rate of Unstable Langmuir Vortices in Shallow Water for Two Different Initial Wave Amplitude Under the Same Wind.